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ABSTRACT

Described are four demonstration/participation laboratories in which students analytically and experimentally evaluated various catheter-transducer blood pressure measurement systems. The activities were included in a graduate level course entitled "Theory and Techniques of Bioinstrumentation," taught by the Department of Electrical Engineering and the College of Veterinary Medicine at Kansas State University. (Author/CP)

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DYNAMIC TESTING AND EVALUATION OF PRESSURE TRANSDUCER-CATHETER SYSTEMS: A STUDENT PROJECT

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Dynamic Testing and Evaluation of Pressure Transducer-Catheter Systems: A Student Project

ABSTRACT

Complementary with a graduate level course entitled "Theory and Techniques of Bioinstrumentation" a laboratory class was offered which, in part, consisted of having the students evaluate both analytically and experimentally various catheter-transducer blood pressure measurement systems. The course was offered by the Kansas State University's Department of Electrical Engineering with teaching and laboratory support furnished by the Department of Physiological Sciences in the College of Veterinary Medicine at Kansas State University.

INTRODUCTION

The Department of Electrical Engineering at Kansas State University as part of their bioengineering program, offers a three hour course entitled "Theory and Techniques of Bioinstrumentation." This course deals with the theoretical aspects of biological signals, electrodes, transducers and processing equipment with special emphasis on the acquisition and recording of electrical potential, pressure and flow measurements. An accompanying one credit hour laboratory emphasizes specific instrumentation and surgical procedures. This paper emphasizes the laboratory component because of its unique organization and content.

A prerequisite for the course is "Control Theory Applied to Bioengineering" which deals with the development of mathematical models used in the study and analysis of physiological control systems. In addition, a basic physiology course is recommended.

The laboratory is taught with the cooperation of the Department of Physiological Sciences faculty in the College of Veterinary Medicine. They provide teaching resources and laboratory facilities. The laboratory meets every two weeks for an entire evening with additional meetings as required. It consists of four demonstration/participation laboratories with a special project that spans the entire semester.

A brief description of the laboratory portion of the course will follow. Each of the four demonstration/participation laboratories will be outlined. These laboratories are designed to give the student an opportunity to observe how some of the instrumentation techniques studied in class are used in practice, as well as to review the physiology involved. A representative laboratory assignment is included in the Appendix. The special project will be discussed in greater detail.

THE DEMONSTRATION/PARTICIPATION LABORATORIES

The objective of the first laboratory is to familiarize the student with the mechanical and electrical events associated with the cardiac cycle in the mammalian heart and also to introduce some of the basic surgery involved in animal experiments. An open thorax procedure is performed on a canine subject after the students have had their first experience with anesthetization, carotid catheterization and tracheal cannulation: simple procedures that end up requiring several hours for the inexperienced. The blood pressure and the electrocardiogram (ECG) waveforms are recorded on a pen writer. This provides the student with the appropriate waveforms for correlation of the heart's mechanical and

electrical activity. Extrasystoles are induced using a stimulator and the effect of the location of the ectopic foci is noted on the ECG. The effect of mechanical rotation of the heart within the thorax on the ECG is also demonstrated.

Atrial fibrillation is induced with the stimulator and the corresponding changes in the ECG and blood pressure waveforms are monitored. The ventricles are then fibrillated and the drastic alterations in both ECG and blood pressure are observed. Each student performs cardiac massage in an effort to maintain adequate circulation. The heart is then defibrillated and the subsequent return toward normal is observed. Throughout the laboratory the students are encouraged to explain the observed changes in the recorded waveforms in terms of the physiology involved.

The second laboratory treats the theory and practice of the electrocardiogram. Objectives include learning proper techniques of electrocardiography, familiarization with the waveforms of the ECG using the standard lead configurations, reinforcement or development of the conceptual basis for the differences between the lead configurations, and observation of the various changes in the ECG waveforms associated with cardiac abnormalities. Leads I, II, and III are used and after normal recordings from each have been obtained, rhythm disturbances are induced with drugs and the resultant changes in the ECG waveforms are noted.

Experimentation with specific electrode types is the topic of the third laboratory. It consists of three parts. The first part demonstrates the use of hook electrodes to observe the electrical activity of single nerve fibers using a laminectomized cat preparation. This

also allows observation of th pattern of discharge from various types of receptors.

The students then participate in a demonstration using plate electrodes to detect activity from motor units in the biceps. Comparisons of these responses with those observed in the dorsal root fibers of the cat are made and the changes in motor unit activity accompanying an increase in skeletal muscle activity is also noted.

The last part of this laboratory employs microelectrodes to record transmembrane potentials in a single cell of a rat diaphragm. The effect of changing the potassium ion concentration in the fluid bathing the tissue on the resting membrane potential is easily observed. Each student is given the opportunity to manipulate the microelectrode and make several recordings.

The objective of the fourth laboratory is to demonstrate the effects of anesthesia planes and several mixtures of inspired oxygen and carbon dioxide on alveolar ventilation and blood gas tensions. Arterial blood samples drawn in several stages of anesthesia from a canine subject are analyzed for oxygen and carbon dioxide tensions and pH. The effects of the different inspired gas mixtures on respiratory rate and blood gas tensions are observed after a stable plane of anesthesia is achieved.

THE SPECIAL PROJECT

The object of the special project was to have the students analytically and experimentally evaluate various catheter-transducer blood pressure measurement systems, and to use these results to furnish the life scientist with the necessary information to enable him to select the catheter that satisfies the requirements for a "best fit" to his system.

The project was assigned at the beginning of the semester and was to be completed by the end of the semester. Several laboratory periods during the semester were allotted to the project, but the students did most of the work on the project during non-scheduled laboratory hours.

The catheter-transducer systems under consideration consisted of: (1) the catheter (the means by which the pressure signal is conveyed from the monitoring site to the transducer), (2) the transducer itself, and (3) the display apparatus (a pen writer, oscilloscope, etc.). A block diagram is shown in Fig. 1. In a system such as this, determination of overall system error involves examination of each component or block of the system to determine how it affects the signal. Characterization of the transducer and the display device is often reduced to reading the manufacturers specifications, if available. Knowledge of these specifications coupled with knowledge of the nature of the signal presented to the transducer yields the desired information. The form of the signal presented to the transducer is determined by the transfer characteristics of the catheter. The life scientist has very little control over the characteristics of a system he uses on a patient, except in his choice of a catheter. If he wishes to minimize the signal error, he must choose a catheter based not only upon the constraints imposed by the clinical situation (size of vessel, position of the patient with respect to the transducer, etc.) but also upon which catheter will transmit the pressure pulse with an acceptable amount of attenuation and/or distortion.

The problem of selecting an appropriate catheter for such a system was presented to the students as a semester project. All of the system

components except the catheter were fixed, and the students were to choose the diameter and length of polyethylene catheter which would represent a "best" choice.

The assignment consisted of four broad stages. The analysis stage was followed by two experimental stages. The final stage consisted of student reports detailing their results and recommendations.

Based on the assumption of an appropriate mathematical model, the students were to predict the effects of various catheters on the overall system performance. The models used were chosen by the students. Several models from the literature had been introduced in class, but the students were not limited to these, and could, if they wished, develop their own models.

After mathematical analysis of several catheter transducer systems, the students were asked to verify the validity of their results in the laboratory by measuring the parameters which they had calculated during their analysis. The experimental design and implementation was left entirely up to the students. The only constraints imposed on them were that their projects had to be completed by the end of the semester and that the experimental design had to be compatible with the facilities available to them. These requirements create a problem similar to one which a practicing bioengineer might face in a clinical situation.

After the experimental and analytical portions of the catheter evaluations were completed, the students were asked to use their results to predict the effects of each system investigated on a blood pressure signal. These predictions were then to be demonstrated by the students on canine subjects in the laboratory. The predictions required that the

students consider the nature of any blood pressure signal which might be encountered (arterial, venous, normal, abnormal, etc.) with respect to frequency components and amplitude.

The problem and a general approach to the solution of the problem were furnished to the students. The analytical portion of the project provided the students with the opportunity to exercise some of the modeling skills which they had acquired during their bioengineering training. The experimental portions of the project gave the students experience in the design and fabrication of testing apparatus and the chance to observe how their catheter-transducer systems actually performed in a clinical situation. They were thus given the opportunity to use their skills in mathematical modeling, systems analysis and design, and physiology, and were able to observe how these areas of their training complemented each other in the solution of a bioengineering problem. In addition, by doing the animal experiments the students were able to gain experience with instrumentation problems from the life scientists' point of view as well as from an engineering standpoint.

When the project was assigned, the class was divided into two laboratory groups. Each group pursued the problem independently. After the project was completed the entire class met with the instructors to discuss the results obtained and to offer suggestions for further study.

STUDENT APPROACHES TO THE SPECIAL PROJECT

Both groups used essentially the same mathematical model for the analytical portion of the project. They assumed a second order lumped parameter model of a fluid filled elastic tube connected to a stiff

diaphragm (the transducer). Various lengths and diameters of polyethylene catheter were chosen for study and the characteristics of each were estimated from the model. Factors such as natural frequency and damping were determined. In addition, the effects of air bubbles and leaks in the system were included in the analysis. Parameter values were estimated from information in the literature [1].

Different approaches were adopted by the two groups for the experimental portion of the project. One group constructed a sine wave pressure generator while the other group designed and built a pressure step generator which they used to measure the step response of each system. (See Figs. 2 and 3)

The group which constructed the sine wave generator used it to measure the frequency response characteristics of each system. The pressure generator consisted of a large diameter acrylic tube filled with water. One end of the tube was covered with a thin tight fitting rubber diaphragm and the other end was fitted with an attachment for affixing a reference transducer and the catheter-transducer system under test. The rubber diaphragm was displaced in a sinusoidal manner by a plunger which was attached to a speaker driven by an amplified sine wave.

The second group utilized a rather simple method for obtaining the step response of the systems under test. The step generator consisted of a sidearm with stopcock fastened to a 100cc glass syringe. The catheter-transducer system was attached to the syringe in place of the needle. The large end of the syringe was sealed with a balloon, which was inflated via the sidearm and stopcock thus producing a positive

pressure. A negative pressure step was produced by bursting the balloon. The response was recorded on a storage oscilloscope. By assuming that the system was second order the group obtained a measurement of damped natural frequency and damping ratio.

STUDENT RESULTS

Both groups obtained results which were essentially the same as far as their recommendations were concerned. There was qualitative agreement between groups and between the analytical and experimental work within each group. Both groups were able to predict which systems would perform satisfactorily during the canine experiment. Both groups, however, indicated the need to expand the experimental effort before making the information available to the life scientist. Samples of the data obtained are shown in Figs. 4-5 and Tables 1 and 2.

STUDENT REACTION TO THE PROJECT

The project generated a great deal of enthusiasm among the students, which resulted in their putting considerable effort into the project. Several students indicated a desire to continue the project after the end of the semester and are doing so at this time. They felt that although they had essentially answered the question initially posed to them, there were other questions and ideas which surfaced during the course of the project which needed to be investigated. Some of these include:

1. determination of the effects on the signal with different methods of attaching the catheter to the transducer,

2. checking the catheter parameters for non-linearity,
3. investigation of signal degradation with time for different systems,
4. design improvements on the test apparatus, and
5. characterization of other systems.

CONCLUSIONS

It is felt that the special project contributed significantly to the value of the overall bioinstrumentation course. The students were given the opportunity to exercise several of their bioengineering skills in a project which could be "completed" in one semester. There was enough literature available on the subject to give the students an ample start on the problem without answering all of their questions for them [2-4]. Some of the students also found out what it was like to "reinvent the wheel", which demonstrated to the class the value of a good literature search in the approach to a problem. The students appreciated the opportunity to undertake a project such as this, and responded with good class participation. Finally, it is felt that by having the student take an active role in the laboratory, interest, and therefore learning, is enhanced.

ACKNOWLEDGEMENT

We wish to express our appreciation for the teaching and guidance efforts of Dr. M. R. Fedde of the Department of Physiological Sciences and Dr. R. R. Gallagher of the Department of Electrical Engineering. It is primarily through their efforts that the course was such a valuable

learning experience. We would also like to acknowledge the equipment and facilities provided by both the Department of Physiological Sciences and the Department of Electrical Engineering.

We would also like to thank Karen Barquest for the illustrations.

FIGURES 1 - 5

and

TABLES 1 AND 2

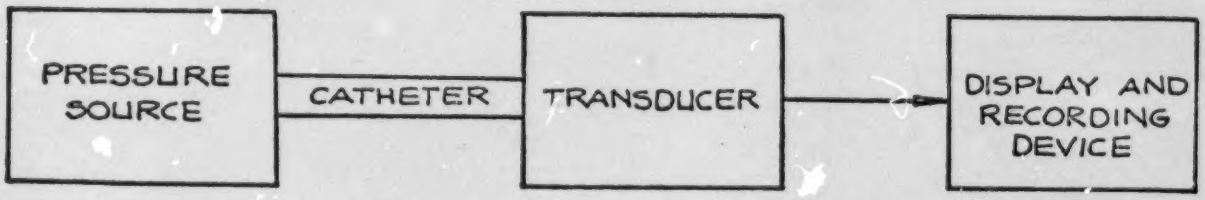


Figure 1. Block Diagram of Pressure Transducer-Catheter Test System.

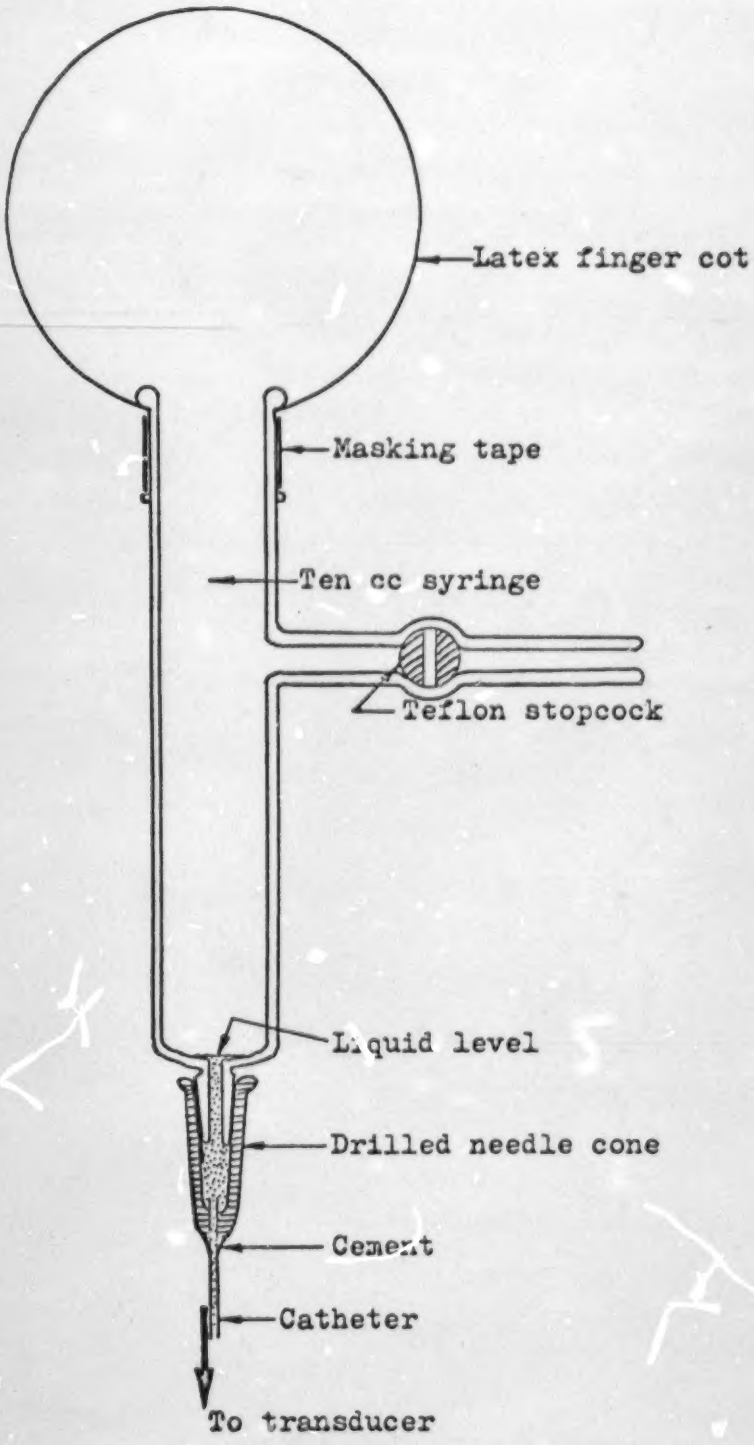


Figure 2. Negative Pressure Step Generator.

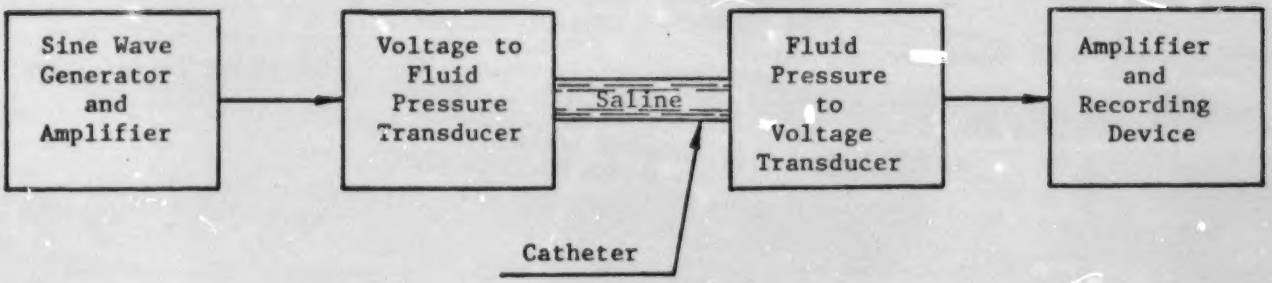
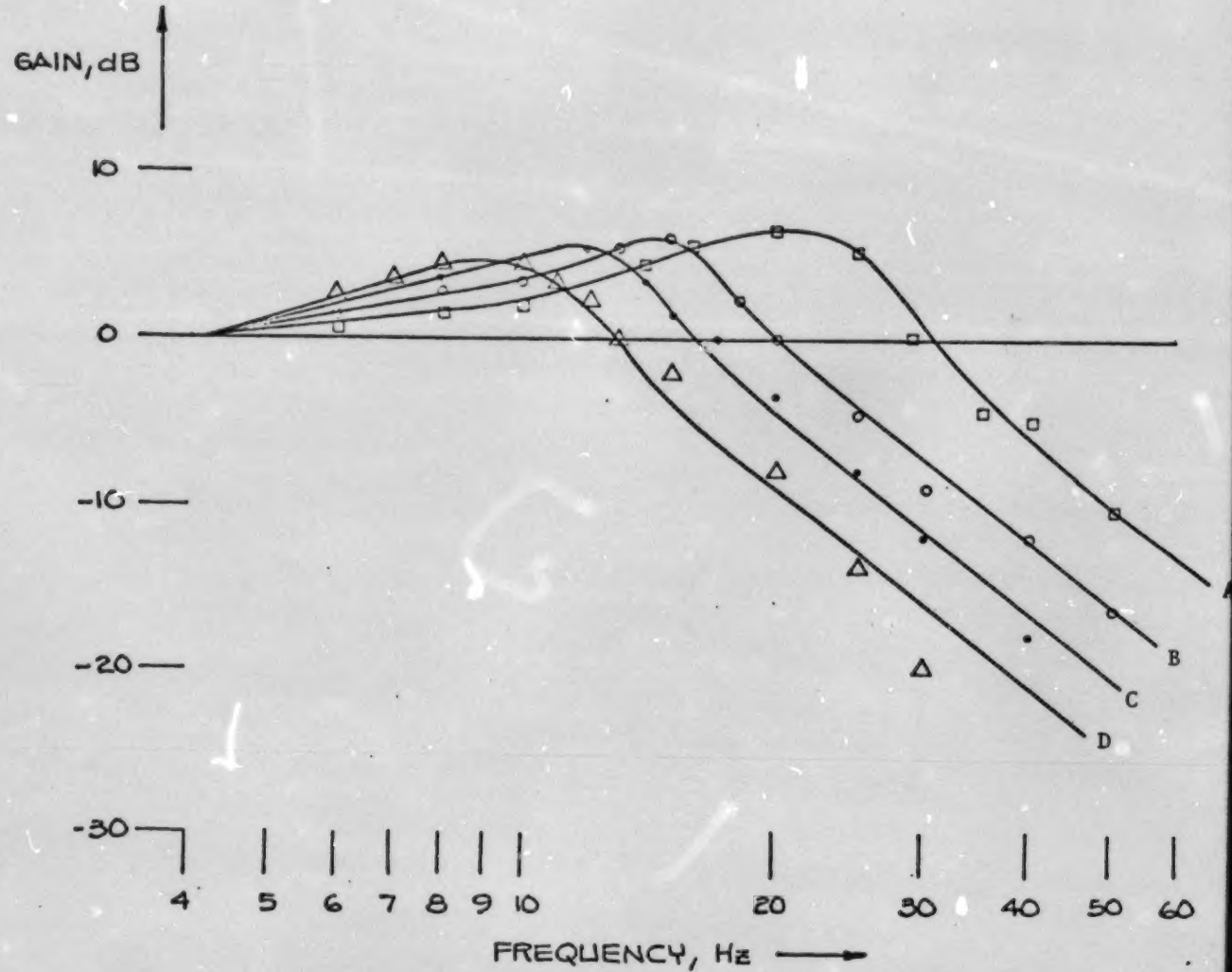


Figure 3. Block Diagram of Sinusoidal Pressure Generator Test System.



	A	B	C	D
ℓ_c (cm.)	15	30	45	60
r_c (PE 90)	.043	.043	.043	.043
ω_n (Hz.)	20	15	12	10
PEAK (dB)	6.8	6.0	5.5	4.5

Figure 4. Typical Sinusoidal Pressure Generator Magnitude/Frequency Data.

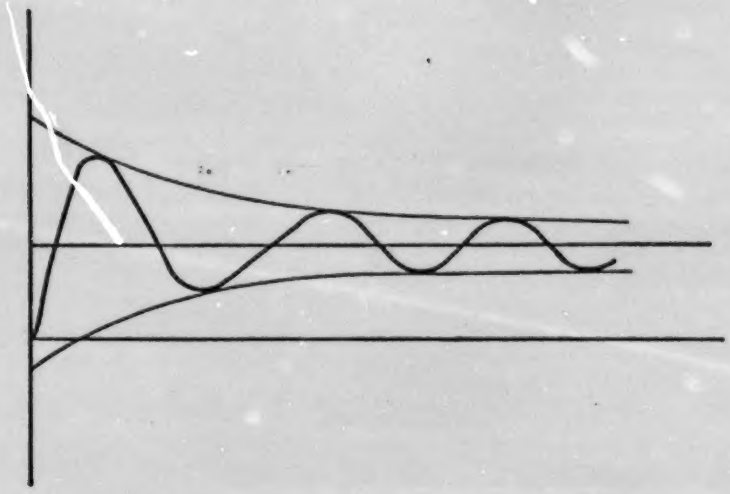


Figure 5.

DAMPED SINUSOIDAL RESPONSE

PE 90 — 45 CM

Catheter	Comments
PE 10, 45 or 60 cm	both lengths have limited bandwidth and should severely attenuate the signal.
PE 50, 45 or 60 cm	both lengths should severely attenuate the signal.
PE 90, 45 or 60 cm	shows 5db gain at 13 hz. may see amplification of dichrotic notch.
PE 160, 45 or 60 cm	shows resonant peak at 12-13 hz. At five times the heart rate (120 bpm) has greater than 5db gain.
PE 190, 45 or 60 cm	the frequency response is flat within 1.5 db up to 20 hz. Should yield a a good signal if the resonance at 60 hz does not distort the signal.

CATHETERS TESTED FOR FREQUENCY RESPONSE

Catheter/needle cone	Diameter, cm		Length, cm					
	in.	out	2	1.5	15	30	45	60
PE 10/#26	.028	.061	-	x	x	-	-	-
PE 50/#23	.058	.097	x	-	x	x	x	x
PE 90/#20	.086	.127	-	-	x	x	x	x
PE 160/#18	.114	.157	-	-	x	x	x	x
PE 190/#18	.119	.170	-	-	x	x	x	x

Note: x denotes combination tested

Table 1. Catheters Chosen for Animal Experiments.

Catheter	Resonant Peak & Frequency	Phase Shift at Resonant Peak	High Frequency Asymptote
PE 90, 15 cm	6.8db, 20 hz	- 72 deg	12db/octave
PE 90, 30 cm	6.0db, 15 hz	- 84 deg	12db/octave
PE 90, 45 cm	5.5db, 12 hz	- 78 deg	14db/octave
PE 90, 60 cm	4.5db, 10 hz	- 80 deg	14db/octave
PE 190, 15 cm	14db, 120 hz	- 96 deg	1db/decade*
PE 190, 30 cm	14.9db, 81 hz	- 72 deg	20db/octave
PE 190, 45 cm	16.7db, 65 hz	- 84 deg	26db/octave
PE 190, 60 cm	12.0db, 60 hz	-120 deg	18db/octave
PE 10, 7.5cm	None, -3db at 1.5 hz	- 60 deg at -3db	3.5db/octave
PE 10, 15 cm	None, -3db at 1 hz	----	----
PE 50, 60 cm	None, -3db at 2 hz	- 39 deg at -3db	13db/octave
PE 50, 2 cm + reducer	10.5db, 74 hz	- 90 deg	26db/octave
PE 50, 15 cm	1.0 db, 6 hz	- 40 deg	7db/octave
PE 50, 30 cm	None, -3db at 2 hz	- 48 deg	4db/octave
PE 50, 45 cm	None, -3db at 6 hz	- 78 deg	7db/octave
PE 160, 15 cm	9.5db, 21 hz	- 90 deg	12db/octave
PE 160, 30 cm	7.0db, 15 hz	- 57 deg	12db/octave
PE 160, 45 cm	8.5db, 13 hz	- 48 deg	9db/octave
PE 160, 60 cm	7.5db, 11 hz	- 90 deg	10.5db/octave

*response had multiple peaks in magnitude and phase.

Note: all high frequency asymptotes had negative slopes.

Table 2. Catheter Frequency Response Data.

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APPENDIX

SAMPLE LABORATORY PROCEDURE

ANALYSIS OF THE MAMMALIAN ELECTROCARDIOGRAM AND USE OF THE ELECTROCARDIOGRAM TO DIAGNOSE CLINICAL CARDIAC PROBLEMS.

I. Demonstration: Analysis of the mammalian electrocardiogram.

A. Generation of extrasystoles; influence of rotation of the electrical axis on the ECG.

1. Objectives

a. To observe the altered electrical impulse when an ectopic foci is produced in the ventricular myocardium.

b. To investigate the relationship between the QRS Complex and the position of the heart in the thorax.

2. Equipment

1 - Small dog (20#)
1 - Physiograph (2 channels)
1 - Stimulator
1 - ECG preamplifier
1 - Blood pressure apparatus
2 - Needle electrodes and extension cables
1 - Large scissors
1 - Small scissors
2 - Large forceps
2 - Small forceps
6 ft. of heavy string
1 - Roll of thread
1 - 10cc syringe
2 - 22 gauge needles
1 - Bottle of alcohol
Large wad of cotton and a few gauze sponges
1 - Hand stimulating electrode and stimulator extension cable
1 - Bone forceps
1 - Harvard respirator
4 - Hemostats, curved and straight
1 - Defibrillator, electrodes and foot switch
1 - 600 ml beaker of saline
1 - Scalpel and blade
1 - Roll of adhesive tape
1 - Small tracheal cannula
1 - Bottle of oxygen
1 - Large plastic bag with T connection to the respirator and oxygen bottle.

3. Introduction

Regardless of the theory held pertaining to the genesis of the waves of the ECG, the record obtained represents excitation and recovery passing over the mass of the heart. The polarities and amplitudes recorded depend on the position of the electrodes relative to the pathway of the excitation and the direction assigned to the recorder for a given polarity applied to a pair of leads. If the sequence of excitation or recovery in the ventricles is caused to be altered, the configuration of the R and T waves will reflect these changes. If, with a slow heart, single stimuli are applied to the base, after the refractory period and before the next beat, an extrasystole will be produced. Since the spread of excitation is in the same general direction as the normal beat, the extrasystole R wave will be upward, like the normal beat if recorded using lead II. However, since conduction of the impulse may travel more in myocardium, where conduction is slower, the R wave will be wider and taller. If on the other hand, a single stimulus is applied to the apex, after the refractory period and before the next beat, the excitation wave of the extrasystole will be inverted, indicating the travel of excitation in the reverse direction. A stimulus if placed midway between apex and base will travel in both directions equally rapidly and little or no R wave will be recorded in lead II. There will also be changes in T waves accompanying the basal and apical beats. Usually the T wave following an extrasystole is opposite in polarity to the wave of excitation.

4. Procedure

a. Channel 1 is to be used for recording ECG led II (right arm, left leg) and channel 2 for blood pressure from the right carotid artery.

b. Anesthetize the dog (1 cc(65mg) pentobarbital sodium/5 pounds body weight) using the cephalic vein. Give about 1/2 of the calculated dose of anesthetic rather rapidly and the remainder to effect using the palpebral reflex and toe pinch as an indicator of anesthetic level. Clip the hair from the ventral surface of the neck and sternum.

c. Make a midventral cervical incision and insert a tracheal cannula. Cannulate the left carotid artery and attach the blood pressure transducer.

d. Insert needle electrodes in the lead II configuration for recording the ECG.

e. Calibrate the blood pressure transducer and ECG (1 cm pen deflection/mv) and take a control record of these parameters at 25mm/sec chart speed.

f. Connect the oxygen bag to the intake of the respirator and then connect the respirator to the tracheal cannula and adjust the rate and tidal volume for normal alveolar ventilation.

g. Make a midline skin incision from the manubrium of the sternum to the xiphoid. Try to prevent severing the ventral cutaneous branches of the intercostal arteries which approach the midline. If one is severed, either tie it off or crush it with a hemostat. Use the bone saw to make a midline entry into the thoracic cavity. Be careful not to damage the internal arteries as they course on the inner surface of the thoracic cavity at the rostral end of the sternum. Ligate these arteries on both sides with double ligatures and cut between the ligatures before opening the thorax wide. When the thorax has been opened, tie a heavy string around the ventral end of a rostral and caudal rib on each side and apply traction to open the thorax wide. Tie these strings to the dog board.

h. Leave the pericardium intact and stimulate the heart at the base of the ventricle with the hand electrode in the following manner. Set the stimulus frequency control at 2 per second so that accidentally turning on the stimulator will not produce ventricular fibrillation. Using only SINGLE SHOCKS of approximately 10 volts, stimulate the ventricles between the T and P waves. Note the configuration of the R and T waves in the extrasystoles produced. Observe the pulse for each extrasystole, depending on the prematurity of the beat. Repeat the procedure in the center of the ventricle and at its apex.

i. An interesting demonstration relating the position of the ECG leads to the electrical axis of the heart can be carried out at this point. While recording lead II ECG, reach into the thorax and pick up the heart, being careful not to restrict diastolic filling. Rotate the heart clockwise and counter-clockwise and note that when the ventricles are generally at right angles to a line joining recording electrodes, the R wave is minimized. Rotate the heart into other positions dorsally and ventrally and observe ECG amplitude.

B. Atrial fibrillation

1. Objectives

a. To precipitate atrial fibrillation and to record the ECG and blood pressure during atrial fibrillation.

2. Equipment

All equipment in part I

3. Introduction

Clinically, atrial fibrillation is one of the most commonly encountered cardiac arrhythmias in man. Unlike ventricular fibrillation it is compatible with life, but if not managed properly, the circulation may be embarrassed by the diminished cardiac output.

During atrial fibrillation, the atria impart no propulsion to the blood contained in them, but they are far from quiescent. All parts are contracting and relaxing as rapidly as recovery will permit, but the contractions are uncoordinated and without effect in pumping blood into the ventricles. Associated with the random contractions of the atrial musculature is an electrical arrhythmia; each contracting element producing its own action potential. Thus the atrial electrogram is random in nature and completely replaces the P wave of the normal electrocardiogram.

In a heart in which the atria are fibrillating, the role of the S-A node as pacemaker is supplanted by the fibrillating atria. The fibrillation frequency is high and is determined by atrial refractory period. The A-V node is constantly bombarded by impulses from the atria and responds as frequently as its refractory period will allow. This imposes a considerable and irregular tachycardia on the ventricles. The tachycardia is of such a rate that there is an inadequate and variable time for ventricular filling resulting in an irregularity of the pulse both in rate and amplitude with failure of some beats to open the aortic valve thus producing a deficit between the ventricular rate, which in turn causes a fall in mean blood pressure and cardiac output. If the ventricles are slowed by a mild degree of A-V block, their reduced rate permits more time for diastolic filling and the pulse deficit will disappear, the mean blood pressure will rise and the cardiac output will increase. If A-V block is produced by left vagal stimulation, the ventricular rate will slow but because of the effect of the vagus to shorten the refractory period will often increase.

In summary, the presence of atrial fibrillation produces many clear cut signs. In the standard electrocardiogram, the P wave is replaced by random rapid oscillations. The R waves are rapid and irregular. The peripheral pulse is

even more irregular, not only in rate but in amplitude as well. Since the ventricles are driven at a rapid rate, inadequate time is available for diastolic filling and many of the ventricular contractions do not open the aortic valves, resulting in a peripheral pulse deficit. A subsequent contraction may occur when the ventricle is overfilled and produce a large stroke volume and a very strong pulse.

4. Procedure

a. Slit open the pericardium. Precipitation of atrial fibrillation can be easily accomplished by stimulating them with the hand electrode (25/sec, 5-10 volts, 2 ms). Record the 2 channels and observe the characteristics of atrial fibrillation. Note and count the pulse deficit in a strip of record.

C. Ventricular Fibrillation

1. Objectives

a. To initiate ventricular fibrillation while recording blood pressure and the ECG.

b. To maintain circulation by compression of the heart (cardiac massage).

c. To defibrillate the ventricles using alternating current.

2. Equipment

All equipment in section I

3. Introduction

The condition of complete asynchronous contraction of the ventricular myocardium is known as ventricular fibrillation. In this state, there is no output from the heart because coordination of muscular contraction has been lost. The heart is far from quiescent, each fiber is contracting and recovering at a rate compatible with its refractory period and each fiber produces an action potential which serves as a stimulus to adjacent recovering tissue. Electrographically, the activity consists of random oscillations of varying amplitude. On palpation, the ventricles have been described as feeling like "a handful of worms."

Fibrillation can be stopped only if the activity of all fibers is arrested. The most convenient method is to totally depolarize the heart by passing a very strong

electrical current through it for a brief time. After recovery from this depolarizing current, impulses coming down the bundle to the fibers will once again cause the ventricles to respond by coordinated contractions.

It is to be noted that many deaths from electrical shock are due to ventricular fibrillation. Ventricular fibrillation may occur during chest surgery by irritation of the myocardium by surgical instruments. It frequently occurs as a result of coronary occlusion. The myocardium is also prone to fibrillate in hypoxia, hypothermia, and when sensitized by some anesthetic agents, notably chloroform.

4. Procedure

a. Place the defibrillating electrodes in the beaker of saline to soak. Turn on the ECG and blood pressure channels. Obtain a control record using one second time marks and approximate paper speed of 1 cm per second.

b. Place your hand around the heart without occluding any vessels and simply feel the manner in which the heart muscle contracts. Observe the direction of contraction of both the atrial and ventricular myocardium.

c. Initiation of ventricular fibrillation. With a stimulus intensity of 10 volts and a frequency of 50 per second, using the hand electrode, stimulate the surface of a ventricle. Observe the cessation of rhythmic contraction and its replacement by fibrillation. Observe the ECG waves and the rapid fall in blood pressure. Proceed to the next step rather quickly so the animal is not without blood for a very long time. If the myocardium is damaged by ischemia, it will not defibrillate.

d. Maintenance of circulation. Manually compress the heart while watching the blood pressure record. Squeeze strongly enough to produce a good circulation and a dicrotic notch on the blood wave. While the operator is maintaining the circulation, turn on the defibrillator and connect the electrodes to it. CAUTION: A defibrillator is a powerful stimulator and if misused can be lethal. The control of the defibrillator is by a foot-switch which is to be activated by the operator only. When the foot-switch is plugged into the jack on the panel, the red danger light will flash, indicating that the strong defibrillating current will flow if the foot-switch is depressed, the AC defibrillator emits a loud buzz indicating that it is providing the output. The foot-switch is to be unplugged at all times when the defibrillator is not used.

e. Defibrillation. Remove the electrodes from the saline and place them firmly around the heart. Plug in the defibrillator foot-switch and note that the red danger signal is flashing. Place the foot-switch within reach of the operator's foot. The operator will then press the foot-switch for about one second while holding on to the electrode handles firmly. He will then remove the electrodes, watch the heart, and observe the ECG and blood pressure return. The foot-switch should be unplugged and the electrodes put back into the saline.